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TRIP REPORT
'91 INTERNATIONAL SYMPOSIUM ON ADVANCED ROBOT TECHNOLOGY ('91 ISART)

S.B. Nickerson

The '91 International Symposium on Advanced Robot Technology ('91 ISART) was attended. It took place on March 5 - 7, 1991 in Tokyo, Japan. While there, visits were made to Power Reactor and Nuclear Fuel Development Corporation, the ETL (Electrotechnical Laboratory of the Ministry of International Trade and Industry - MITI), the MEL (Mechanical Engineering Laboratory of MITI), Hitachi Ltd. Mechanical Engineering Laboratory, and TEPCO (Tokyo Electric Power Company) Brochures from the institutions visited and documentation for the conference, are available from the author.

The '91 International Symposium on Advanced Robot Technology

Background

The purpose of this symposium was to mark the end of the Japanese eight year (1983 -1990) "Large-Scale National R&D Project" on Advanced Robot Technology funded by the Japanese Ministry of International Trade and Industry (MITI). Selected pages from a Project brochure are attached.

This large ($180 million) national project involved two national laboratories, eighteen industrial companies, many from heavy industry, and two non-industrial companies. The objective is to develop the capability of being able to construct a series of teleoperated robots operating under

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conditions hazardous to humans. The fundamental technologies are developed in the national labs and the applied systems are developed in industry. Under this program the fundamental underlying technology and subsystems were developed, detailed design was done and models were built for testing purposes, but no actual working robots for field testing were built.

The three target applications for the project were:

1. A nuclear plant operations robot: A commercial version of this robot would be able to move about in a nuclear power plant environment and be capable of carrying out high level operations such as inspection, maintenance and repair, while receiving high-level support of a remote operator. The robot has four legs and will be capable of going up and down stairs. There are two arms, each with a multi-fingered hand capable of dismantling and repairing equipment such as valves, pumps, etc, using normal human tools and with the aid of a remote human operator. Control will be a combination of human and autonomous functions. The research areas were communications, hardening against radioactivity, reliability, power source, manipulators, sensors, and body shape. Communications will be by means of a laser so that the robot will always have to be within line of sight of a transmitter. As part of this element of the overall program they have developed a prototype of a wall climbing robot which uses suction plates for adherence to the wall and has, as an application, the inspection of large tanks containing highly radioactive liquids. The purpose is to look for corrosion and small leaks so that repairs can be made before accidents.

2. An undersea petroleum production facility robot: The goal is to have an undersea robot take over most of the oil exploitation platform maintenance and inspection operations. The duties will be: visual inspections, cleaning, non-destructive inspection (with ultrasonics, for example) and installation operations (opening and closing of valves, etc). They will be partially teleoperated and partially autonomous.

3. A robot for fire fighting and disaster prevention at petroleum production facilities: This robot would be expected to perform those duties now performed by humans during accidents or fires at petroleum production facilities. It will have to be able to withstand high temperatures, smoke and the presence of toxic, flammable, explosive or corrosive gases. Control will be mainly by teleoperation, with some autonomous capability for standard operations.

Research was divided into four areas: one specific to each of the three target application areas mentioned above and an area with elements common to all three application areas.

The Symposium

The symposium lasted three days, during which there were 77 papers, 56% by Japanese and the balance by foreigners. In contrast the attendance was 388 with 86% from Japan. Canadians were

the most numerous foreign group (12) and there were only three from the USA, all from different universities.

The table of contents for the symposium is attached.

The Japanese papers were for the most part related to the Advanced Robot Project and were given by representatives of industry whereas the foreign papers were much more wide-ranging and, mostly, given by academics. This made it almost seem like two conferences, which must have been disappointing to the hosts. There was a small exhibit hall showing posters and models. It was empty during the time that I visited it, perhaps a reflection of the lack of foreign industrial representation.

Subsystems for each of the three applications were developed by different industries. The subsystems were brought together for videos, and then returned afterwards to the industries that made them. The results were impressive although it was clear that not all subsystems were incorporated in the final demos. For example, the communications system was not incorporated in the nuclear robot and the disaster prevention robot did not have its arms.

The subsystems for the three application areas were, in many cases, complementary, a reflection of the fact that the subsystem design was more important than the complete system and that this project was designed to be a learning exercise. Japanese industry could then do it correctly, by themselves, on the second try. For example, the disaster prevention robot used a laser based vision system while the nuclear robot used a passive stereo vision system; the disaster prevention robot used a cumbersome 6-leg, 6-wheel locomotion system while the nuclear robot used a 4-leg quadrupedal walking mechanism; and the nuclear robot uses a laser based communication system while the undersea robot uses a fibre optic cable based system.

Although many of the subsystem choices were good if your goal is just to investigate the technology, for the following reasons I do not believe that the nuclear robot is close to being of practical use in an operating nuclear plant:

1. The choice of a hand and finger end effector for the arm. The hand was used to grip a wrench and the fingers to twist off loosened nuts. From the demo videos, it was obvious that the nuts were very loose and well lubricated. I very much doubt if the system could cope with a real situation where the nuts are often frozen.

2. The robot has four legs with a quadruped gait. This was chosen so the robot could go up and down stairs, walk over obstacles and bend its legs to get under overhanging obstacles. However, the resulting platform is not always stable. This is evident because the brochure and the videos always showed the robot supported by four wires. In fact during a live demonstration at Hitachi after the conference, I twice saw the robot fall over, and caught by the supporting wires. Legs are a very expensive option, in terms of complexity, decontamination and weight, compared to tracks or wheels.

3. The robot was not battery powered, which would limit its usefulness.

4. The laser-based communication system was never integrated with the rest of the system, so that the tether was used for communication.

Many of these limitations will, I am sure, be overcome in the next generation of robots. It is much more realistic to expect to get it right the second time, than the first time. The Japanese approach seems to be the government funding the first generation and letting industry, motivated by profit, fund the second generation.

Mechanical Engineering Research Laboratory (MERL)
Hitachi Limited

MERL is located in Tsuchiura City, near Tsukuba Science City, about 50 miles from Tokyo. MERL staff of about 680 conducts research on basic engineering science in areas such as heat transfer, fluid mechanics, vibration, robots and strength analysis. Its mission is to contribute to the development of new products in collaboration with Hitachi's manufacturing groups. Hitachi spends about 5.8% of its total sales on R&D.

The first demo they showed was of the platform for the nuclear operations robot, which they developed for the Advanced Robot Technology Project. It was stripped to just the legs and platform - no arms, no plastic covering and no housing for the arms. It was enclosed in a cage about 8 feet wide and 60 feet long. There was an infrared beam along the cage attached to a kill switch to keep the robot from getting too close to the cage fence. There were also four overhead wires to catch the robot in case it fell over and a tether for communications and power. They were to show the platform walking, running and climbing stairs, but during the running demo the robot fell over twice and it was never completed. I believe they had trouble with a belt attached to one of the feet.

Also shown was a "smart manipulator", which was not working and a tracked mobile robot which has been mothballed (for tax reasons). The latter item was made about 1986 and they see no future for it.

They have about 40 people doing robotics. They have not done much in mobile robotics since the MITI project stopped, but they are looking for applications of the technology in the areas of deburring, hospital applications and space applications. They have no new plans for the walking robot. Five or six of their people will be working on the new Japanese micro-robotics project.

Mechanical Engineering Laboratory (MEL) of MITI

Located in Tsukuba Science City, MEL has 276 researchers and conducts research in the areas related to Mechanical Engineering, including robotics.

They carried out some of the background work for the MITI Advanced Robot Technology including a 4-wheeled robot with active suspension, a 4-legged robot with no knees and a biped

robot with no knees, the first two demonstrated during my visit. The active suspension vehicle has feedback mechanisms, based on input from an inclinometer and gyro, that actively controls the vehicle's suspension, controlling unwanted motions of the vehicle's platform. The 4-legged robot uses a new type of link mechanism in which each leg is rigid and has 3° of freedom.

They plan to be involved in the new Microrobot project where they will be building prototypes for evaluation.

In their work do not consider applications at all, so are not following up on their Advanced Robot Technology work. They will let industry use their technology if it wishes.

Electrotechnical Laboratory (ETL) of MITI

The ETL is also located in Tsukuba Science City. It has a staff of 648 doing research in the areas of energy technology, information technology (including robotics), electronics, and standards and measurement technology.

While there I visited the Computer Vision Section (where I met Pierre Boulanger who was on a long term visit from NRC), the Autonomous Systems Section and the Intelligent Machine Behaviour Section, all in the Intelligent Systems Division.

The most interesting demo at ETL was of a manipulator - vision system used to disassemble a valve. The laser based vision system was used to recognize the position and orientation of the valve, and the arm used this information and pre-programmed procedures to do the disassembly.

Power Reactor and Nuclear Fuel Development Corporation (PNC)

Mark Tinkler (Metallurgical Department) and I visited the O-arai Engineering Centre, which is located in Mito, about 100 miles from Tokyo. PNC has about 2800 employees and its role is to help Japan shift its nuclear reactor program from a light water reactor (LWR) to a fast breeder reactor (FBR). PNC is developing a wide range of plutonium utilization technologies: R&D on the fuel cycle; reprocessing of LWR spent fuel; fabrication of uranium-plutonium mixed oxide fuel; development of the FBR and the advanced thermal reactor; R&D on uranium exploration, uranium enrichment, treatment and disposal of high-level radioactive waste. They also have a mandate to commercialize the various technologies that they develop.

The reason for the visit is their interest in AI and robotics as technologies that they see as ways to enhance the safety of their nuclear facilities, and to improve their economy and efficiency. Their goal is to fully automate as many facets of operation as possible, reducing the risks of human error and exposure to radiation.

In robotics they are looking at remote inspection and maintenance devices such as pipe crawlers, automated methods to handle uranium and plutonium, and teleoperated equipment to decontaminate and decommission nuclear plants. They demonstrated various robotic devices, during the visit. Talks were given on the ARK Project and on Mark's turbine blade welding robot.

Tokyo Electric Power Company (TEPCO)

Together with Mark Tinkler (Metallurgical Research) TEPCO, a large electric utility serving Tokyo and area, was visited. Based on electricity generated, TEPCO is the third largest, world wide, generating about 2.0×10^{11} kWh in 1989. Ontario Hydro by comparison was the sixth largest and generated 1.3×10^{11} in 1989.

At 350, their research group has about half the number of people as Ontario Hydro Research Division and 8 times the budget. They tend to contract their research activities out to private industry, rather than do it themselves.

They are engaged in the following robotic related activities:

1. A live-line distribution system robot: They have a real working system consisting of a truck, an insulated boom and a cab, on which the arms are mounted and from which an operator can see, change end effectors and control arms. There are 2 arms and a small crane, controlled either by a master slave system or a 6-axis joy stick. The system has force feedback. They feel that they are progressing towards a completely automated system. A test operation, involving putting a new switch on a pole, cutting two wires and replacing them with two new ones, took 2.5 hours and four people by hand compared to 2.5 hours by the robot and one person. The system will be in service in March 1992. It cost about $11 Million to develop over nine years.

2. Robotic inspection tool for transmission lines: The concept is to have a robot move along a de-energized transmission line to inspect for defects using an eddy current probe and a magnetic resonance sensor. The requirements are that it be self-propelled, it be able to pass towers, it be able to travel a distance of 10 towers without new batteries and that it sense defects. Presently it is a tethered laboratory demo not yet tested on a real line. It carries with it a folded up guide rail which extends and attaches to towers when it encounters them. It then runs along the rail taking about 15 minutes in total to bypass a tower. It has been designed by Toshiba to work in 36 km/hr winds.

3. In their thermal plants they use a variety of robots: a flue gas pipe cleaning robot, a gas pipeline inspector, a main steam pipe crawler, a robot for the external inspection of boiler tubes, a water circulation line painting robot, a large arm to clean and inspect a turbine blade and a robot to take off sea shells from underwater intakes. The shell scrapper robot weighs 1 tonne on land, is tethered and teleoperated.

4. They have developed a number of robots for their nuclear operations: TEPCO was involved in the MITI Advanced Robot Technology Project, a mobile robot with inertial guidance (1982 - 84, Hitachi, in mothballs), a 5-legged tethered mobile robot with AI guidance (1983-5), an intelligent biped robot (1985, Hitachi), an inspection robot for nuclear power plants, and a monorail mounted, inspection robot that uses an infrared camera to take temperature profiles and inspect for steam leaks (Hitachi, 1988 - 90). The monorail inspection robot is the only one in use and is regarded as the most useful; the rest were never used. They regard the Advanced Robot Technology nuclear robot as too big, too heavy and not sophisticated enough to use in a real plant. They think it will be many years before the functionality of mobile robots will be developed to the stage where they will be useful.

Talks were given on the ARK Project and on the Mark's turbine blade welding robot. The best way for us to interact with them would be for us to present a joint proposal with a Japanese Company to TEPCO. Tepco would be interested in specification writing and in finding applications with us, but not in joint R&D.

Approved:

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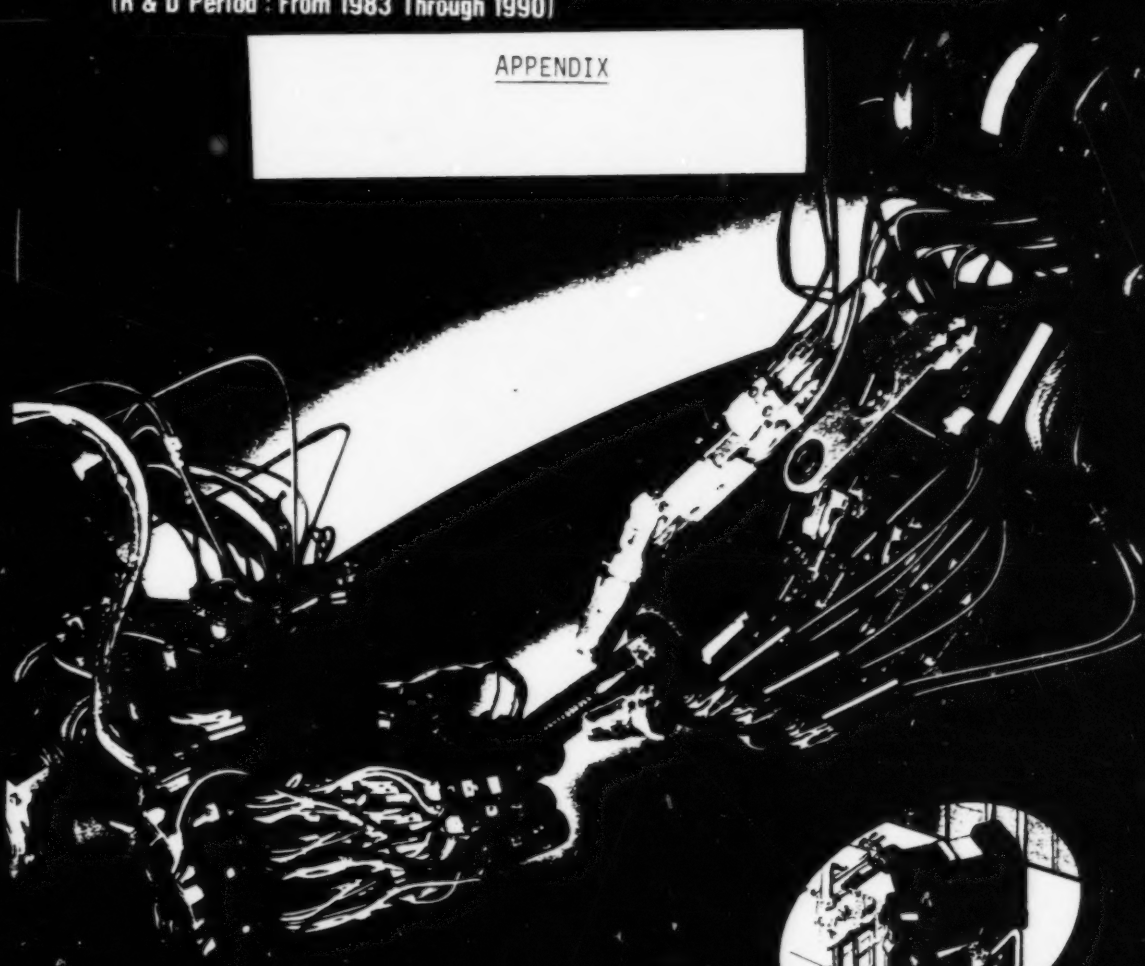
LARGE-SCALE NATIONAL R & D PROJECT "ADVANCED ROBOT TECHNOLOGY" PROMOTED BY THE AGENCY OF INDUSTRIAL SCIENCE AND TECHNOLOGY MINISTRY OF INTERNATIONAL TRADE AND INDUSTRY

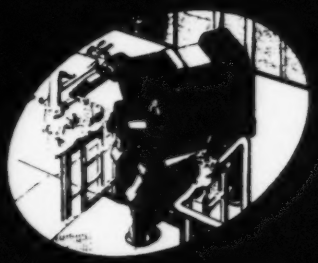
ADVANCED ROBOT TECHNOLOGY

(R & D Period : From 1983 Through 1990)

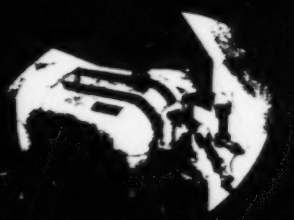
APPENDIX

CHALLENGE FOR THE





Nuclear Power Plant Robot



Subsea Robot

Disaster-Preventive Robot

91-260

ARTRA ADVANCED ROBOT TECHNOLOGY RESEARCH ASSOCIATION

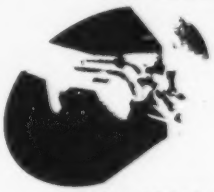
R & D PROJECT BACKGROUND AND OBJECTIVE

In the modern life enjoyed today, there are many human labor operations which are unable to be carried out or accessed without sufficient defense equipment and devices to achieve security.

These included, for example, work in a high radiation field in nuclear power plants, undersea operations for ocean exploitation and fire fighting and rescue operations. This demand for extremely sophisticated operations, as well as that for similar types of work, which at the present can only be accomplished by men, is increasingly seen in today's society.

In consideration of such a background, the "ADVANCED ROBOT TECHNOLOGY" Project aims to develop robots which can carry out inspection, maintenance, and rescue operations, or other work in the field of nuclear power plant, undersea, and disaster-preventing. Such projects need much money and time for development and entail much risk, so this project is being promoted by the large-scale national R & D project system of the Agency of Industrial Science and Technology, MITI. (AIST)

Advanced Robot for Nuclear Power Plant Facilities
(Nuclear Power Plant Robot)



Advanced Robot for Support of Ocean Oil Exploitation
(Subsea Robot)

Advanced Robot for Fire Fighting and Disaster Prevention
(Disaster-Preventive Robot)

OUTLINE OF R & D PROJECT

The Advanced Robot Project has been directed toward establishing technologies that will be required by commercialized robots needing the maneuverability and general-purpose adaptability to carry out inspection, maintenance, rescue operations, and other broadly diversified and highly complex jobs speedily and accurately, either under direct supervision or by remote control in nuclear power plants, undersea operations, disaster-preventing, or any other environment that defies direct human intervention due to high radiation dosage, high water pressure, high temperature, or other highly hazardous factors.

To achieve the above objectives, not only has the development been targeted for nuclear power plants, undersea operations, and disaster-preventive fields for robots, but R & D activities have also been assigned for the technologies required in common by the three fields of application cited, as basic technologies.

It is neccessary to use the technologies accumulated in the many engineering fields in robotics' motion, sensor, judgement, control etc., to develop the most advanced technologies and to put these technologies to practical use for R & D. It is realized that close cooperation between government, research institutions and private companies is the most important factor to successfully achieve this project.

This project has been carried out by national research institutions (Mechanical Engineering Laboratory of AIST and Electrotechnical Laboratory of AIST) and Advanced Robot Technology Research Association (comprised of 18 companies and 2 organizations promoted by the Agency of Industial Science and Technology, MITI.)

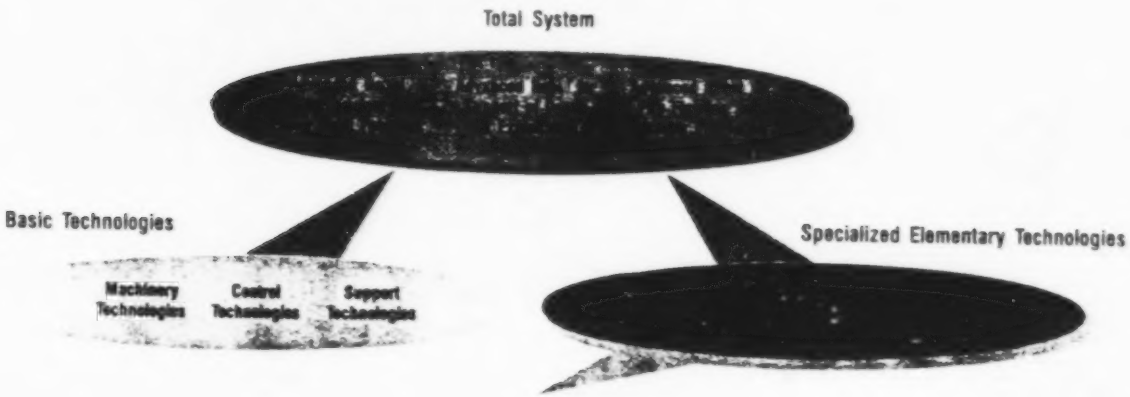
MEMBER

- Ishikawajima-Harima Heavy Industries Co., Ltd.
- Oki Electric Industry Co., Ltd.
- Kawasaki Heavy Industries, Ltd.
- Kobe Steel Ltd.
- International Robotics and Factory Automation Center
- Komatsu Ltd.
- Sumitomo Electric Industries, Ltd.
- Toshiba Corporation
- JGC Corporation
- NEC Corporation
- Japan Power Engineering and Inspection Corporation
- Hitachi, Ltd.
- Fanuc Ltd.
- Fujitsu Ltd.
- Fuji Electric Corporate Research and Development, Ltd.
- Matsushita Research Institute Tokyo, Inc.
- Mitsui Engineering & Shipbuilding Co., Ltd.
- Mitsubishi Heavy Industries, Ltd.
- Mitsubishi Electric Corporation
- Yaskawa Electric Mfg. Co., Ltd.

PROJECT SCHEDULE

Research Theme \ Fiscal Year		1983	1984	1985	1986	1987	1988	1989	1990
Advanced Robot for Nuclear Power Plant Facilities	Specialized Elementary Technologies		Conceptual and Basic Design		Trial Production and Experiments		Trial Production and Experiments		
	Total System				Concept	Conceptual Design	Detailed Design	Manufacture and Experiments	
Advanced Robot for Support of Ocean Oil Exploitation	Specialized Elementary Technologies			Conceptual and Basic Design	Trial Production and Experiments		Trial Production and Experiments		
	Total System					Conceptual Design	Detailed Design	Manufacture and Experiments	
Advanced Robot for Fire Fighting and Disaster Prevention	Specialized Elementary Technologies			Conceptual and Basic Design	Trial Production and Experiments		Trial Production and Experiments		
	Total System					Conceptual Design	Detailed Design	Manufacture and Experiments	
Basic Technology	• Machinery Technology • Control Technology • Support Technology		Development of Basic Technologies				Establishment of Basic Technologies		

(Note) The original project schedule regarding Total System for Disaster-Preventive Robot was changed to finalize it by Conceptual Design.



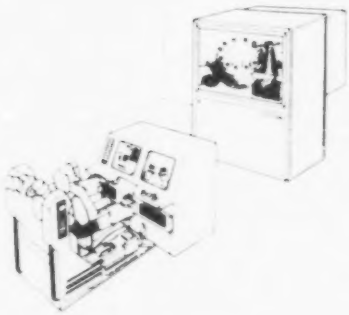
DEVELOPMENT RESULT OUTLINE

Regarding Nuclear Power Plant Robot and Subsea Robot, individual Total Systems have been established and Verification Systems equipped with the technologies for locomotion, vision and manipulation have been manufactured.

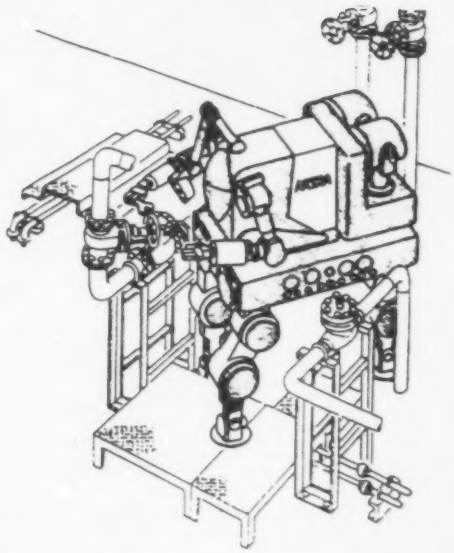
For Disaster-Preventive Robot, only Elementary Technologies has been developed due to delay in its R & D start on the project schedule.

Details on the development result for each robot are presented in the following pages.

Total System Research Achievements

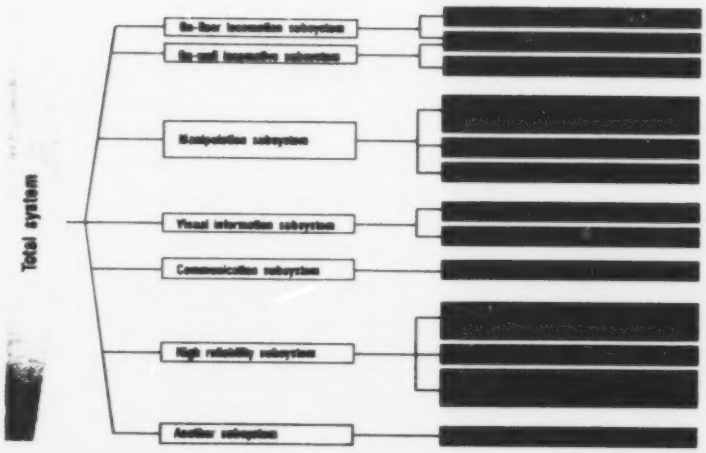


Operator console conceptual view



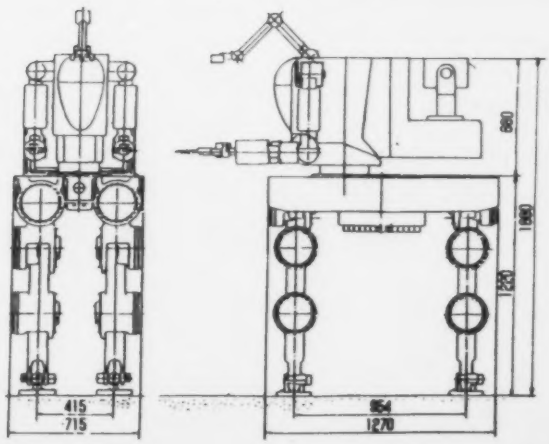
Robot conceptual view

Elementary technologies development



Major robot parameters

Items	Parameters
1. Configuration • Dimensions (mm) • Weight	1,270L × 715W × 1,610H/ 1,880H variable About 700 kg
2. Locomotion • Form • Speed • Function	Quadruped walking type Max. 300 m/h Up and down staircases Striding over impediments Passing underneath overhead obstacles
3. Manipulation • Form • Payload	Two-arm four fingered manipulator 20 kgf / both arms
4. Vision • Form • Function	Binocular vision / Motion sterio vision Object recognition
5. High Reliability	Functional fail-safe control Robot health-care Fault tolerant robot controller
6. Power / Communication • Power • Communication	External power supply Optical wireless / Optical fiber type

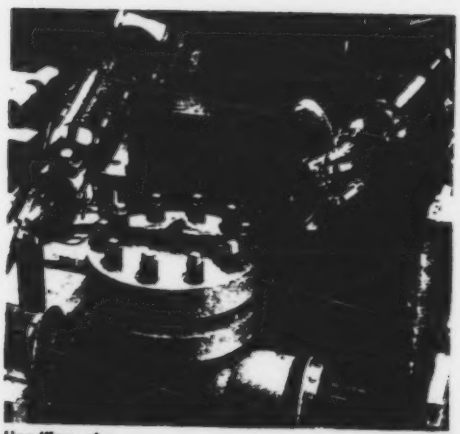


VERIFICATION TEST ILLUSTRATION

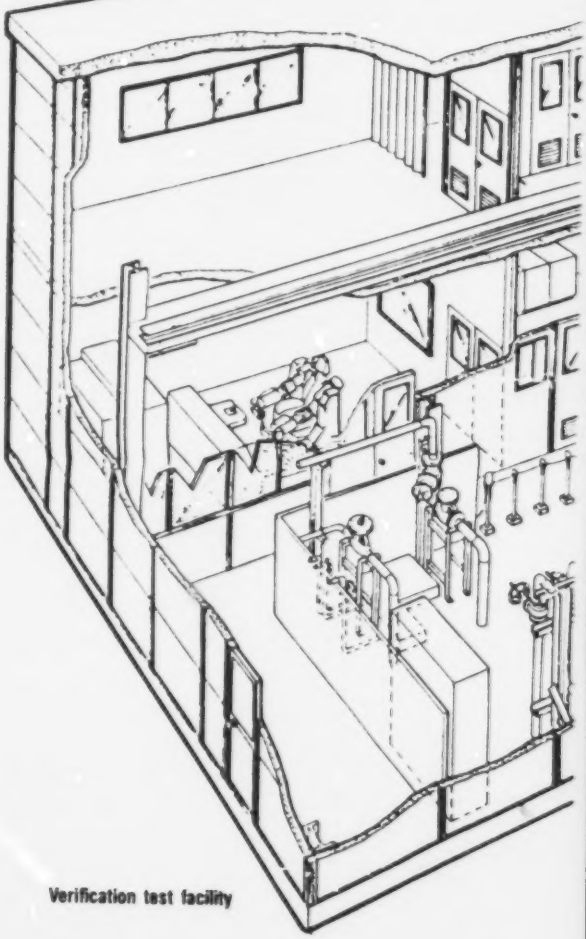
- Remote control robot supported by autonomous function
- Ability to pass staircase, weir, door, etc.
- Ability of implementing valve overhaul work
- One-man operation

Fastening a nut with a wrench

Turning a nut with fingers

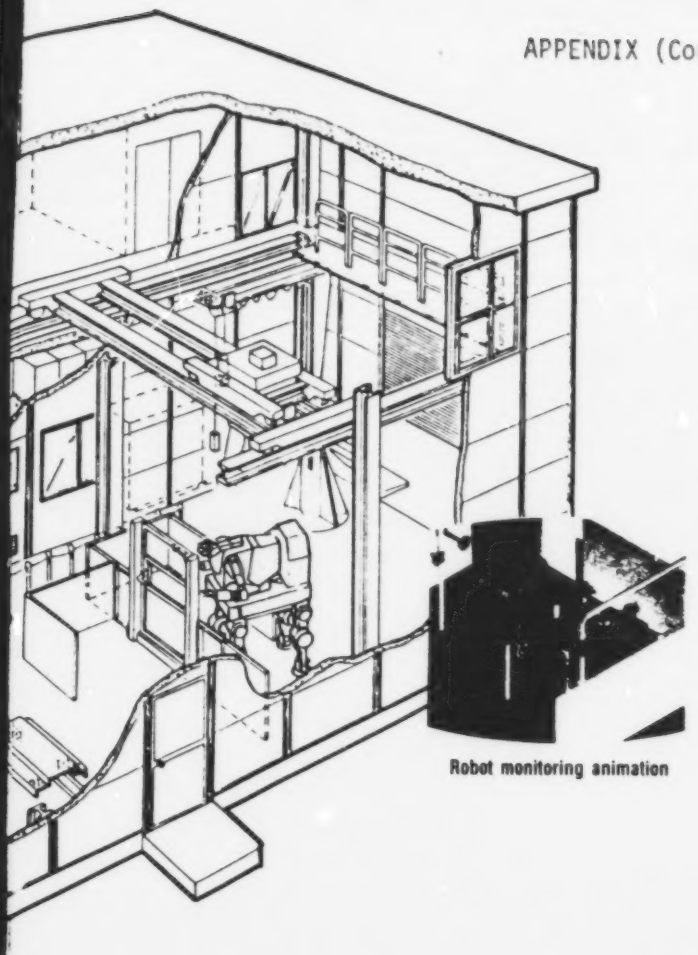


Handling wire

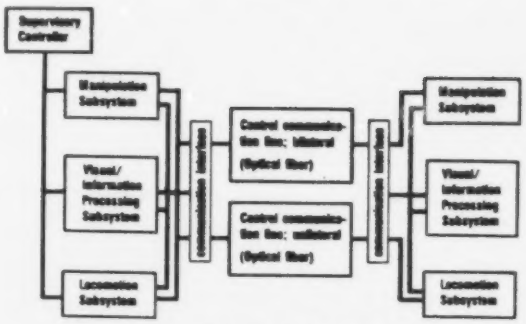


Verification test facility

Opening a door



Robot monitoring animation



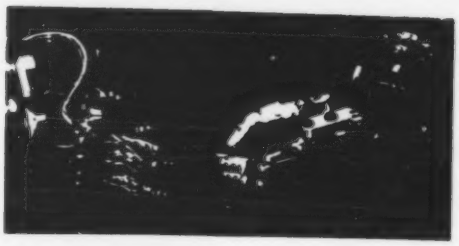
System block diagram

Operating the robot by one person

Striding over impediment

Climbing over impediment

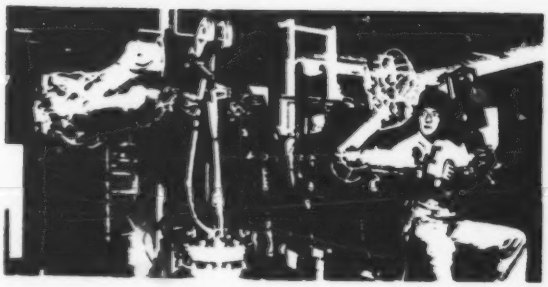
Manipulation



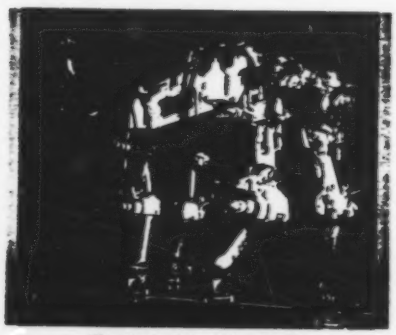
Teleoperation
- Multi-sensory
- Bilateral control

Autonomous control

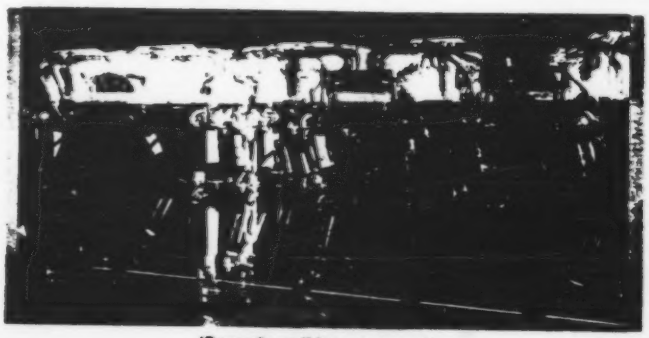
Example of defined commons



Quadrupedal Walking

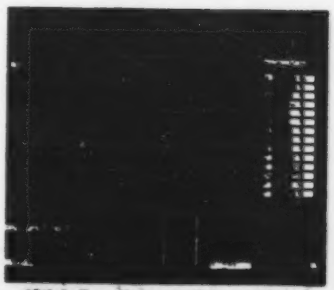


(Quadrupedal mechanism)

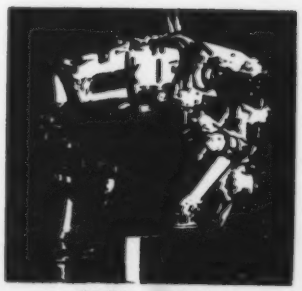


(Dynamic walking on ground)

Items	Specifications
Weight	300 kg
Leg length	0.9 m
Speed	2.5kms/h (Dynamic walking on ground)
Structure of joints	Total 16 joints (each leg has 4 joints) hip & kneejoints: Hydraulic Actuator Foot joints: 3 DOF gimbals joint
Control system	Hierarchy structure Leg motion control is based on parallel processing



(Stick line diagram of leg motion)



(Walking motion)

[Step over an obstacle]

On-wall Locomotion (Verification test for on-wall locomotion)

Stepping over obstacle

Transfer onto wall

Specifications of on-wall robot

Type	Twin mobile disks with wheels
Size	0.7m wide × 1.0m long × 0.8m high
Total weight	130kg
Traveling speed	About 2km/hr
Traveling mechanism	Large torque, small size lightweight electric actuator
Manipulator	Multi sensing bilateral system (Handling load, 2kg)
Vision system	Observation by twin cameras/Motion stereo vision
Communication	Optical wireless communication system
Curvature of wall surface	2 meters radius and up

• Technology developed through this project

Low friction, high efficiency vacuum seal
Friction coefficient = 0.2
Air leakage = 0.1 m³/min

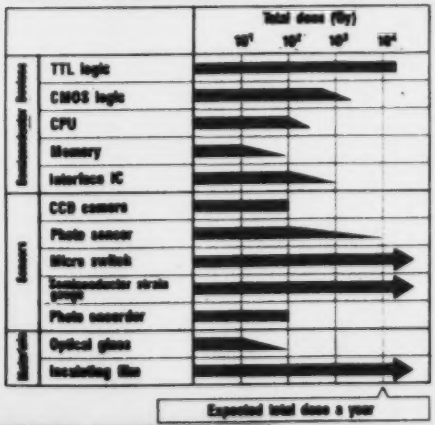
Radiation Resistance

Estimation for radiation Resistance on parts and material for robots

Objective
- Estimate radiation degradation for semiconductor devices, etc. exposed to gamma ray radiation
- Develop a prototype database, applicable to design of parts selection and maintenance for robvots

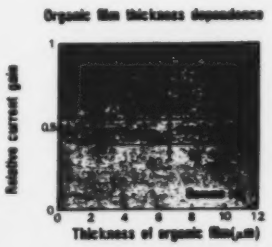
Outline
- 48 parts for robots were tested
- Changes in their characteristics were measured by on-line measurement system under irradiation
- Measured data were compiled into prototype database

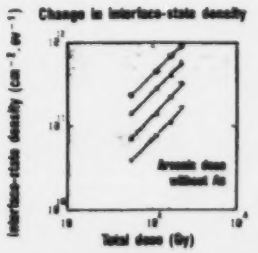
Results of radiation resistance for parts and materials for robots

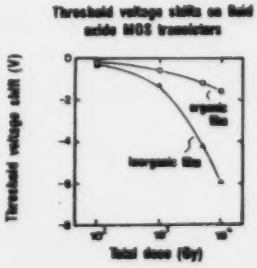


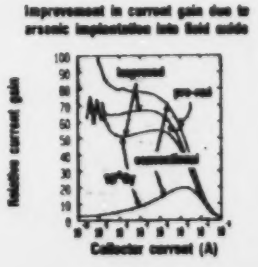
Radiation-hardened bipolar transistors

requirement: Total dose of more than 10^4Gy.
Controlling raidation effects:
① Organic films for passivation.
② Arsenic implantation into field oxide.









Proceedings
'91 International Symposium
on
Advanced Robot Technology
('91 ISART)

Tokyo, Japan

March 5-7

Organized by:
Japan Industrial Robot Association (JIRA)
Advanced Robot Technology Research Association (ARTRA)

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